Steam and Gas Power Systems
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Module No # 07
Lecture No #33
Gas Turbine Cycle – Modifications

Hello I welcome you all in this course on steam and gas power systems today we will discuss about the modifications in a gas turbine cycle important to improve the efficiency or output of the cycle it is not often decided to improve the efficiency of the turbine. Sometimes it is decided to have high output of the turbine may be sacrifice of some part of the efficiency of the turbine. So we will discuss both the things.

So means of improving the efficiency and the output they are four methods through which we can improve or the cooperation of these turbine methods through which we can improve the efficiency and output of the turbine the one is open cycle with regeneration open cycle with regained open cycle with intercooling effect of modifications.

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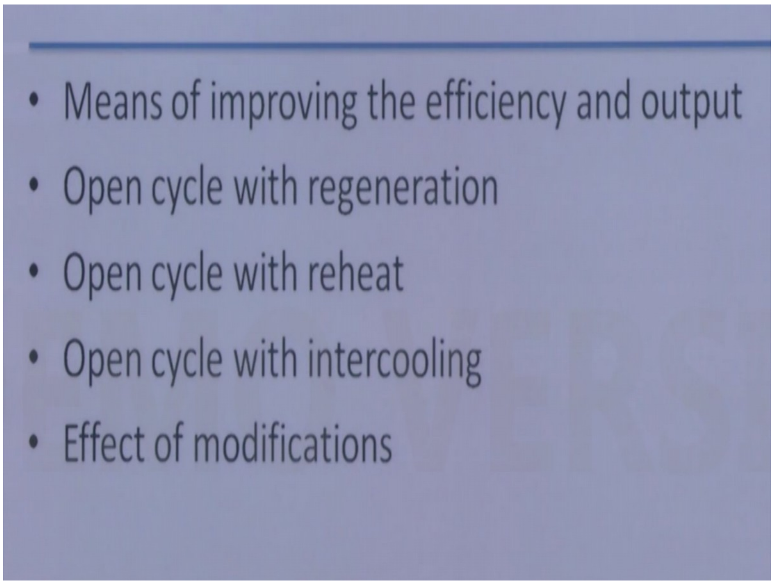

We will discuss later on but these three processes whether we can also use for improving the performance design the performance of gas turbine cycle we will start with regeneration.

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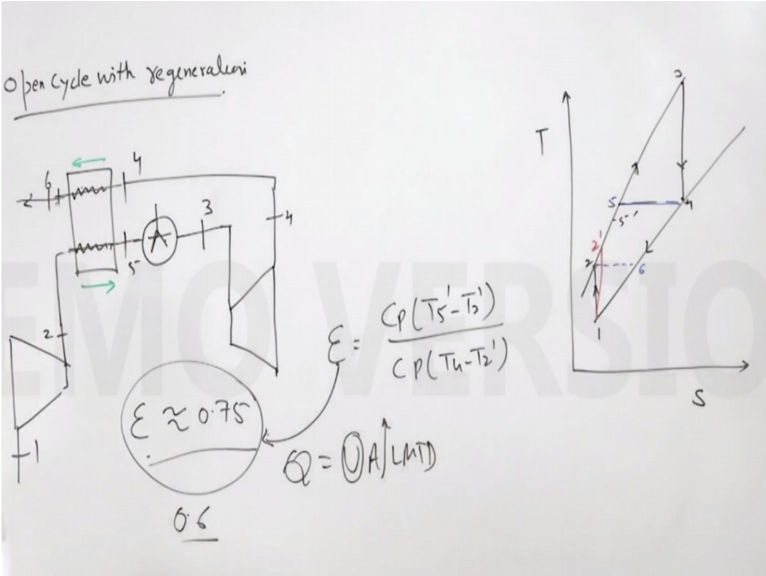

Now if i draw the temperature entropy diagram of a gas turbine cycle state 1 to state 2 now two to three heating takes place. We are taking state three now three to four expansion takes place right and in the open cycle gas turbine this is temperature and this is entropy in an open cycle gas turbine the gases emerging from the turbine are same to the surroundings in the open cycle gas turbine.

Air is sucked into the system from the surrounding fresh air it is compressed and then heat is added in the combustion chamber and the then the fuel fuses they expand in the turbine and exhaust of turbine is end to the surroundings but here the gases which are leaving the turbine are at very high temperature. If you compare the temperature of compressed gas and this is wastage of heat now if this gas can be used for heating the outlet of the compressor or the gas emerging from the compressor we can save some amount of energy.

Right if i show you the arrangement of compressor and turbine on the shaft. It is typical like this three is a compressor air is sent from the surroundings and air is discharged then air goes to the combustion chamber where fuel is injected from the combustion chamber and this is state 2 and after the combustion chamber the temperature is increased to state 3 and then it goes to the turbine and state four is here now i want to heat to the gas available at state 2 at the exhaust of this gas turbine.

So this exhaust is passed through a heat exchanger regenerator so heat exchange arrangement is made in a regenerator right and this air emerging from the compressor is heated up to the temperature five. So after state 4 it passes through the gas exchanger and state 6 is attained now temperature of state 4 = temperature of state 5 the hot gas is the counter flow heat exchanger.

So the gases entering from this side hot side the temperature of hot fluid entering the exchanger in ideal case it can become the temperature of cold fluid leaving the heat exchanger but in actual practice this does not happen in actual practice this is a heat exchange regenerator is a heat exchanger of gas to gas type of heat exchanger in gas to gas heat exchanger.

The effectiveness is very low the effectiveness of this heat exchanger is 0.75 the effectiveness of heat exchanger is actual heat transfer the actual get transfer let us say we are not getting 5 we get 5 dash so actual heat transfer is from T2 dash to sorry T5 dash to T2 dash so CP T5 dash – T2 dash and maximum possible heat transfer that is CP.

T4 - T2 dash that is the maximum possible heat transfer and this is gives the actual heat transfer and this for the realizing this effectiveness = 0.75 large surface area required because it is air to air heat exchanger. So overall heat transfer position is very low so overall heat transfer is Q = UA LMTD. So U is low high value of area has to be taken now we will write expression for thermal efficiency when regeneration is (()) (06:11) turbine now for ideal processes.

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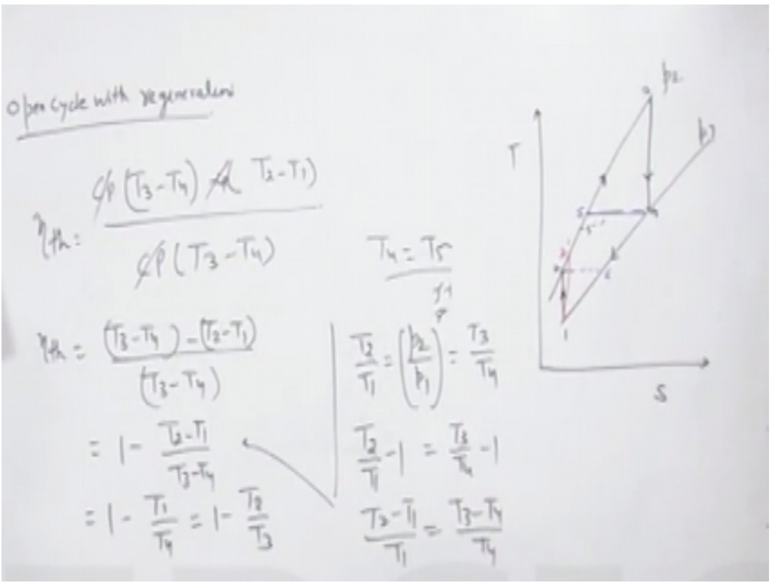

Turbine efficiency is net work output that is T3 – T4 this is turbine output minus compressor input T2 - T1 multiplied by CP this is CP this is in fact this is H3 - H4- H2 - H1 this expression we have taken CP delta T right and divided by heat transfer in the process that is now CP T3 - T4 T3 - T4 because T4 = T5.

Here we are consuming all ideal processes we are not consuming any irreversibility here so T 3 – T4 so thermal efficiency is T3 - T4 because CP and CP will be cancelled out minus T2 - T1 divided by T3 – T1 and that will give 1 - T2 – T1 divided by T 3 – T1 now again T2 by T1 = this is P2 and this is P1 = P2 by P1 raise to power gamma - 1 over gamma.

Because these processes are adiametic processes = T3 by T4 right so T2 by T1 -1 = T3 by T4 – 1, T2 – T1 by T1 = T3 – T4 by T4 now T2 – T1 divided by T 3 – T4 if you are using this equation you will be getting - 1 T1 by T4 or = -1 T2 by T3 and either of this two we can take.

Now we have come to the final expression thermal efficiency = 1 - T2 by T three right now we can do further manipulation 1 - T2 by T1 into T1 by T3 right or we can say pressure ratio now this T2 by T1 can also be taken as CT and this T1 by T3 can be taken as T maximum temperature ratio because T1 is the lowest temperature and T3 is the highest temperature right.

So thermal efficiency can also be expressed in terms of CT divided by this is not T max actually this is 1 by T max because T max is T3 by T1 ok. So this is divided by T max once CT = 1 suppose in a case CT = 1 there is no compression or no energy spent in the compression in that case thermal efficiency is 1-1 by T max that is Carnot efficiency.

Right and when CT = this is maximum temperature ratio this is T max = CT square and then we can have thermal efficiency = 1 -1 upon CT that is simple gas turbine the efficiency of the simple gas turbine this is efficiency of the Carnot cycle working between temperature range this and this right so this is one way of increasing the performance of a gas turbine that is by regeneration now output of the turbine can also be increased by using reheat cycle that is open cycle with reheat.

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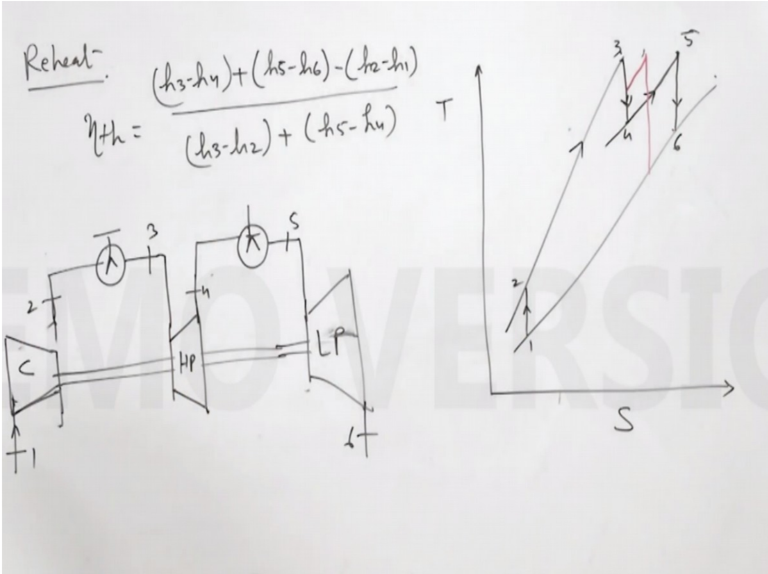

In case of reheat as we have done in case of steam turbine that i will draw it again in pressure and entropy state 1 to state 2 that is compression 2 to 3 as written here now 3 to 4 expansion in high pressure turbine then again reheating up to temperature T3 this is temperature 5 = temperature 3 and then expansion at 6 this is known as reheat cycle because expansion is taking place in two stages.

If we draw if we wish to draw the schematic of this then the schematic is going to be like this a compressor at state 1 the air is sucked in the compressor the air is compressed to state 2 then it goes to the combustion chamber then we get state three at the exhaust of the combustion chamber then expansion takes place inside they are all on a single shaft expansion takes place in a high pressure turbine.

Now this is state 4 then there is gain combustion chamber where again heat is added 4 to 5 and we get state 5 and 5 to 6 expansion again it takes inside a turbine 5 to 6 the arrangement is like this right so in this case this reheat cycle does not increase efficiency in gas turbines it does not increase efficiency because heat is added at two stages yes the symbol of this compressor has to be change.

Here it has to be like this (()) (14:13) compressor this is the high pressure turbine and this is the low pressure turbine now output is in two stages enthalpy at 3 - enthalpy at 4 enthalpy at 4 - enthalpy at 5 now if you want to have thermal efficiency of the cycle in that case the net output is H 3 – H4 + H5 – H6 – H2 – H1 divided by H3 –H2 + H5 – H4.

This is going to be the thermal efficiency of this turbine now the question arises to what pressure this expansion takes place so the output is seen suppose the expansion takes place up to here then reheat will go suppose expansion does not takes place up to state four it takes up to here so the cycle will be reheated the expansion will be like this if the expansion takes place further expansion takes place and the cycle is going to be like this right.

So under which case the output is going to be the maximum now in order to find this first of all we will write the equation for the output output of the turbine output of the turbine can be taken from here this is the output of the turbine because anyway this is going to remain fixed H2 – H1. So output of the turbine is work of the turbine is H3 - H4 + H5 - H6 that is CP T3 - T4 + CP T5 - T6 right.

Now CP T3 1 – T4 by T3 + CP T5 1 – T6 by T5 now this is pressure 1 this is pressure 2 and at state 5 we can takes pressure X some pressure X now work of the turbine again = CP T3 1 - T4 by T3 it means 1 - PX by P3 raise to power gamma - 1 over gamma ok and + CP T5 1 - T6 by T5 it means P3 is nothing by P1 only P2 only this is P2.

Sorry this is P2 this is P1 right so pressure is pressure raise from P1 to P2 ok so it is T6 by T7 so T6 by T7 is P1 by P X raise to power gamma - 1 over gamma now this for the sake of convenience. We take this as A constant A because this is constant right once we consider this as the work of the turbine can be writtened as CP T3 1 - PX by P2 raise to power PA + CPT5 1 - P1 by P X raise to power A.

We have to find the optimum value of PX optimum means for which the output is maximum so we differentiate work of the turbine with respect to DTX when differentiation take place then CP T3 ok here T3 = T5 so we can always take T3 1- A PX to power A - 1 P2 raise to power - A right + CPT3 1 – T1 raise to power A TX to power - A.

Sorry 1 PX to power - A 1 + A PX to power 1 A - 1 because this PX raise to power - A - A become + A PX to power - A - 1 this is PX and P1 raise to power A . Right now this is going to be = 0 this is going to be = 0 then the final expression will be like this 1 - A PX raise to power A - 1 P2 - A + 1.

Say this one will not be there when we differentiate this one will also disappear A remains the constant so it is - A PX raise to power A - 1 P2 raise to power A + A PX raise to power - A - 1 and P1 raise to power A right and this is going to be = 0 and then we get PX raise to power A - 1 P2 raise to power - A = PX raise to power - A.

-1 P1 raise to power A this gives PX raise to power A – 1+ A + 1 = P1 raise to power A and P2 raise to power A and this will be cancelled out. So PX raise to power 2 A is going to be = P1 raise to power A and P2 raise to power A or PX is under root P1 and P2 right and the pressure ratio is 4 so this pressure ratio has to be 2 and this pressure ratio has to be 2 or pressure ratio is 9 then this pressure ratio has to be 3 and this pressure ratio has to be 3 right.

So this is how we can get the intermediate pressure for maximum output in a reheat cycle now in addition to this we can do intercooling also cycle intercooling now in cycle intercooling instead of reheating while compressing the work is saved while compressing now state 1 to instead of going from directly from state 1 to state 2 the fluid is compressed.

Let us say from the state 1 to state 7 right and then it is cooled again to state 8 and then 8 to state 2 so it is something like this that compression is done in two stages that is known as open cycle inter cooling in intercooling.

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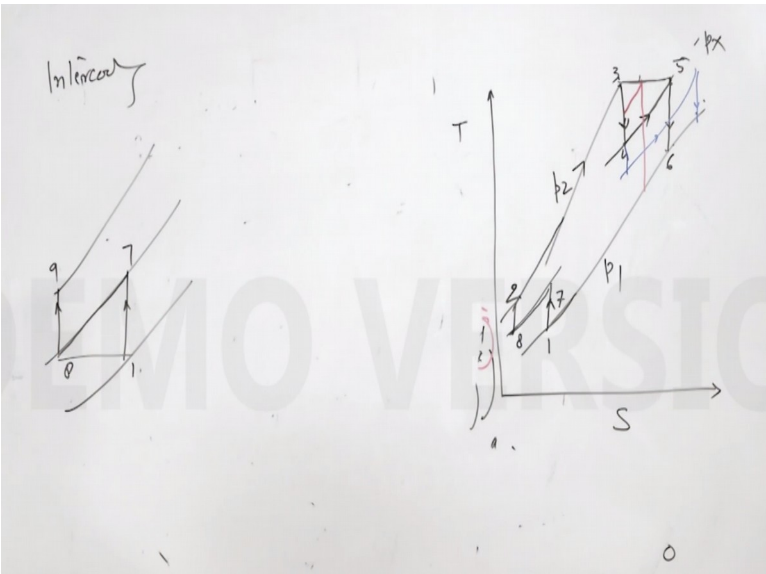

From there is an intermediate state so state 1 to state 7 the compression takes place then the air is cooled to state 8 temperature of 8 in ideal case temperature at 8 = temperature at 1 and then again compression takes place 8 to 9 right and if you want to find the optimum pressure for this same methods we will use and then we will get optimum pressure or PX = under root.

Again P1 and P2 product of P1 and P2 but intercooling what happens in intercooling when we do intercooling the heat edition in increases work input in the compressor is reduced that is the benefit and what we are losing we are losing the heat this much of heat which has to be additionally added in the combustion chamber right so this is about and we can have a combination also we can have a cycle.

Which has intercooling as well as reheating arrangement and it can also have a arrangement of regeneration that is also possible so depending upon the requirement combination of all these three can be used in order to improve the performance of the cycle or in order to improve the output of the cycle.

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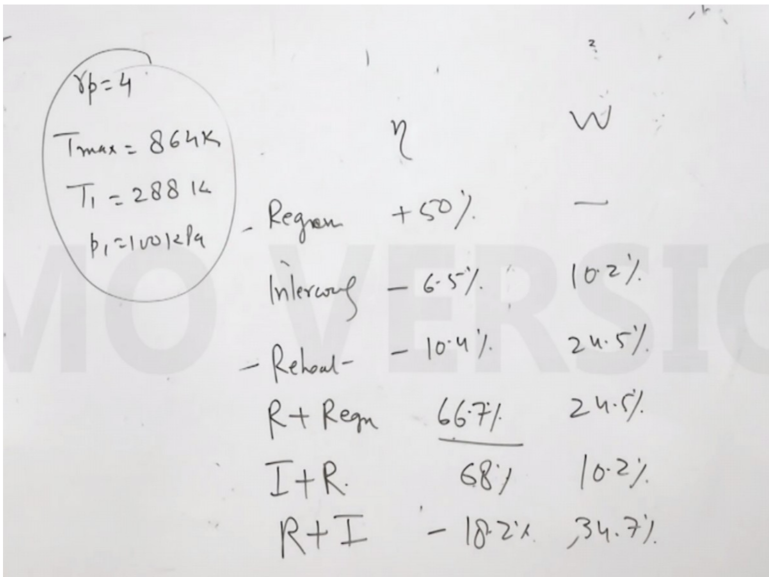

Now if we compare will respect to the efficiency and the output efficiency of the turbine and output of the turbine and a typical case pressure ratio = 4 is taken maximum temperature 874 Kelvin is taken T1 is 288 Kelvin and P1 = hundred kilo Pascal right. If we compare the performance then regeneration can improve the performance by 50 % output lot of end the output right but it can increase the efficiency by 50 % intercooling.

Intercooling will reduce the efficiency by 6.5% but improve the output 10.2% why it is improving the output because the work spent or the energy spent in compressing the gas is reduced reheat it reduces the efficiency 10.4 % but improves the output up to 24.5% if i mean expansion takes place in both the first stage expansion takes place at optimum pressure.

Then again expansion takes place to the lower pressure now reheat plus regeneration if we combine these two together then efficiency can increase up to 76.7 % and work 24.5 %. So if we use regeneration efficiency and the work output both can increase if we combine reheat and regeneration intercooling and regeneration it is 68 % and 10.2 %.

Right as reheat plus intercooling will reduce the efficiency 18.2 % and 34.7 % and these values are for particular this type of input we can have a table for different type inputs and depending upon the requirement we can choose the process modification process which can improve the performance of gas turbine that is all for today thank you very much.